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AERONAUTICAL RESEARCH LABORATORY

MELBOURNE, VICTORIA

Guided Weapons Report 013

GUIDED WEAPONS DIVISION SPIN TABLE FACILITY: SPIN TABLE CONTROL SYSTEM

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SUMMARY

The control system developed and used successfully over the past two years for controlling the angular velocity of the Guided Weapons Division spin table is described. The philosophy underlying the design is discussed, followed by description of the specific hardware and software components and the performance of the system as a whole. The report forms part of the permanent record of the GWD spin table facility development.

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1. INTRODUCTION

In 1987, a new initiative commenced within Guided Weapons Division (GWD) to recommission an existing spin table to form the basis of a new infrared seeker evaluation facility, currently configured for AIM-9L/M Sidewinder Guidance and Control Section (GCS) simulation. The basic mechanical, optical and optomechanical features have been described elsewhere.[1]

In the present report, the control system developed and used successfully over the past two years for controlling the table angular velocity is described. The philosophy underlying the design is discussed, followed by description of the specific hardware and software components that have been designed and installed, and the performance of the system as a whole. The report forms part of the permanent record of the GWD spin table facility development.

2. BACKGROUND

It is not the intention to claim that the control system that has been implemented necessarily represents an optimal solution. Instead, the design reflects both the limited availability of resources that existed during the early stages of the spin table development program and the concurrent lack of electronic effort. It was therefore natural at the time to adopt a software-oriented control system design. In spite of such early restrictions, a practical and versatile control system has nevertheless been developed, well capable of handling the diverse range of requirements that exist at the present time within the AIM-9L/M Sidewinder simulation program.

2.1 Control Algorithm

The philosophy from the outset was to adopt a design in which the table was controlled by a dedicated personal computer, thus enabling the significant advantages that both software and hardware upgrades could readily be implemented in future on a needs basis. The control algorithm is based on the system diagram shown in Figure 1, the left hand side representing the software control blocks and the right hand side the torque motor drive and spin table load. The motor is characterised by motor constant K_T and back emf constant K_B. The total series resistance and inductance are denoted by R and L respectively, the viscous damping coefficient by K_f, static frictional torque by γ_f and the moment of inertia of the load about the spin axis by J. The motor is driven by a proportional plus integral (PI) controller with angular rate feedback. The values of the control system gain k and the integral filter scale factor T are set within the software. Either a rate gyro or a position encoder can be used to supply actual angular rate information $\dot{\theta}_a$ to be compared to the demanded rate $\dot{\theta}_d$.

The basic performance characteristics of this simple control system can, by judicious application of appropriate approximations, be readily ascertained. Since the table rate (< 1 rad/s) is small compared to the electrical rates ($R/L \sim 500$ rad/s), the inductive lag can be neglected. Similarly, the viscous damping term can be neglected compared to the moment of inertia. The frictional torque can be also neglected in the first instance, at least for the present purpose of drawing out the principal properties of the system.

With the above simplifying approximations, it can readily be shown that

$$\frac{\dot{\Theta}_d(s)}{\dot{\Theta}_a(s)} = 1 + \frac{T\,s}{k(1+T\,s)}\left[K_B + \frac{R\,J\,s}{K_T}\right]. \tag{1}$$

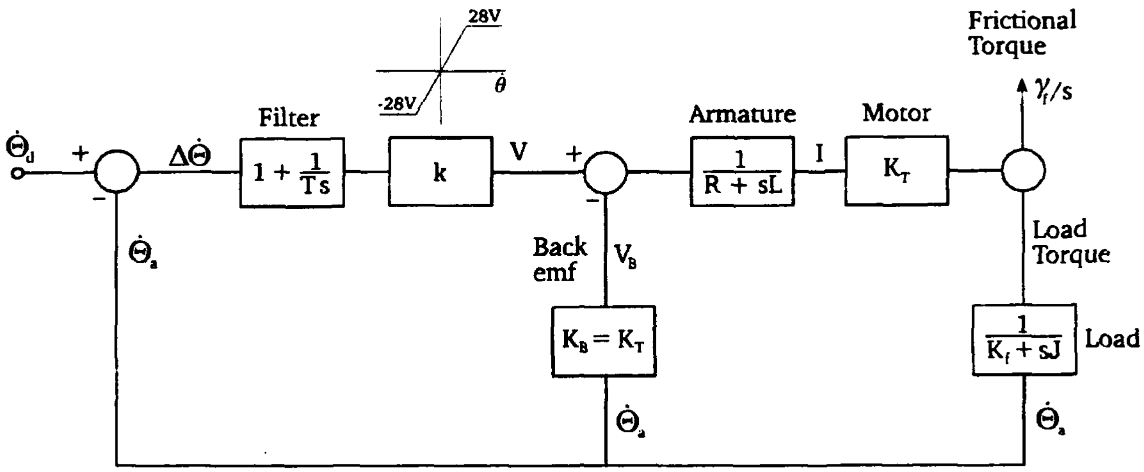


Figure 1 Spin table speed control system

Zero steady-state ($s = 0$) velocity error is therefore predicted, consistent with the PI control function.

In practice, the frictional torque term cannot be ignored, leading to the need for finite motor current even at zero speed. It can readily be shown that when the frictional term is reincluded a velocity error is predicted irrespective of the presence of the integral term in the input filter. The practical function of this term is therefore to damp the high frequency electrical noise introduced when speed control data is transferred through the slip rings to the control computer, rather than to reduce the steady-state velocity error. For this purpose, it has been convenient to gate the integral in such a way that the past errors are accumulated over a finite rather than infinite time into the past. In general, the past time interval has been set at 50 ms, sufficient to damp the electrical noise contributions but insufficient to affect the system temporal response.

Given the above mode of operation, it is reasonable to expand the initial noise-free assessment of the control system by reintroducing the frictional torque γ_f that was earlier omitted and by neglecting instead the integral term (by setting T to infinity). It can then readily be shown that the system responds according to the equation

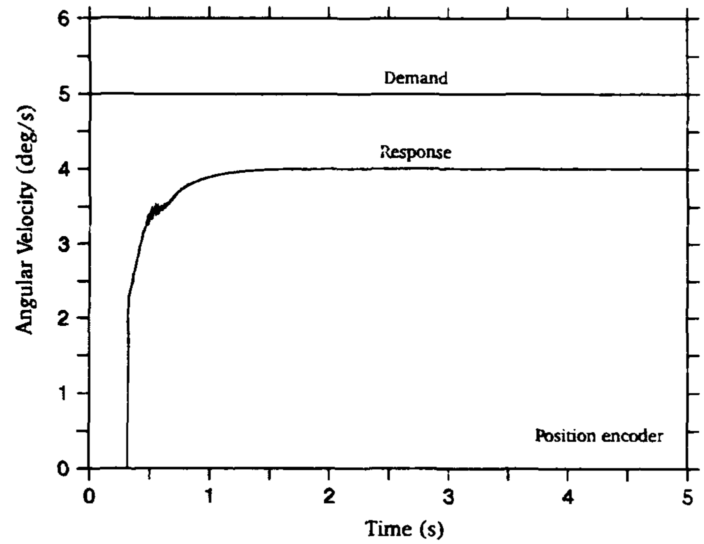
$$\dot{\Theta}_a(s) = \frac{\dot{\Theta}_d(s) - \dfrac{\gamma_f R}{k K_T s}}{1 + \dfrac{K_B}{k} + \dfrac{J R s}{k K_T}} . \tag{2}$$

This equation may readily be solved for the step-function case $\dot{\theta}_d(t) = \dot{\theta}_0\, u(t)$, where $u(t)$ is the unit step-function. By transforming to the time domain, we obtain the system step-function response in the form

$$\dot{\theta}_a(t) = \left(\dot{\theta}_0 - \frac{\gamma_f R}{k K_T}\right)\left(\frac{k}{k + K_B}\right)\left(1 - e^{-t/\tau}\right) \tag{3}$$

where the time constant τ is defined by

$$\tau = \frac{J R}{K_T\,(k + K_B)} . \tag{4}$$



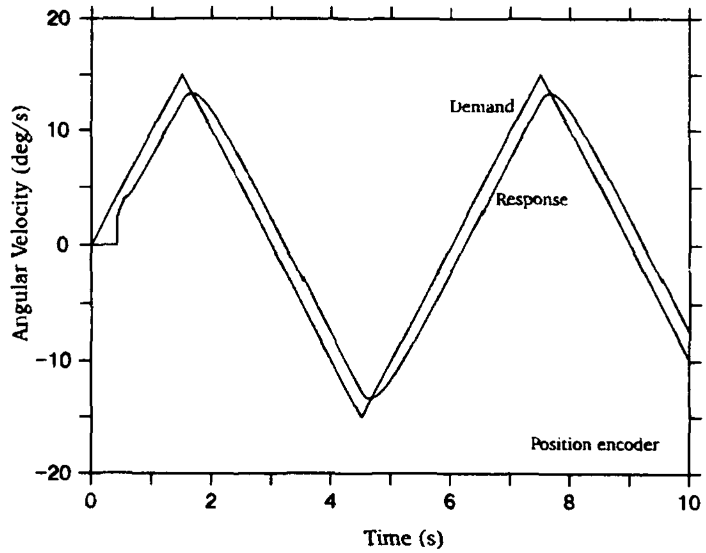


Figure 2 Examples of output from the control system simulation program

A first order lag is therefore predicted accompanied by a finite steady-state error, the magnitude of which is influenced both by the back emf and the frictional torque. It can be seen from (3) that the contribution from each of these components is reduced as the gain is increased. In practice, the table turn-on response is limited by the maximum torque available from the motor and hence a slew towards the demanded angular velocity is observed rather than an exponential rise.

While the above analysis is useful for identifying the influence of the principal system variables, it can by no means be regarded as a full representation of the problem at hand. No account has been taken of the effect of stiction (variation of γ_f as the angular rate is reduced towards zero), nor of the discrete nature of the angular velocity readout. It might therefore be expected that the system would be amenable to a more detailed analysis through use of standard z-plane sampled data control system techniques.

At the time when the system was first being developed, however, the only means of sensing the

Table 1 TORQUE MOTOR CONSTANTS

Parameter	Value	Units
Peak Torque	35.3	N m
Motor Constant	1.37	N m $W^{-\frac{1}{2}}$
Torque Sensitivity K_T	1.50	N m A^{-1}
Back emf Constant K_B	1.50	V rad^{-1} s
Static Friction	0.54	N m
Rotor Moment of Inertia	0.0168	N m s^2
No Load Speed	3.0	Hz
Viscous Damping Coefficients:		
Zero Impedance	1.89	N m rad^{-1} s
Infinite Impedance	0.008	N m rad^{-1} s
Stall Voltage	28.1	V
Peak Current	23.4	A
Armature Resistance R_a	1.2	ohms
Inductance L	4.0	mH
Electrical Time Constant L/R_a	3.3	ms

table speed was by differentiating the output from a position encoder mounted on the spin table shaft. In that case, discrete samples at constant angular increments are recorded rather than at the constant time increments required for implementing the standard z-plane techniques. It was therefore decided that it was preferable to simulate the system operation by utilising the PC-286 computing power that was available in order to numerically integrate in the time domain, adding such practical details as stiction, the discrete nature of the angular velocity measurement process and the PI control capability as actually implemented. In this way, not only was it possible to develop a close simulation of the practical system operation long before the hardware could be interconnected, but also the opportunity became available to assess the algorithms required for driving the hardware in real-time, again through extension of the simulation software.

It is not the intention to discuss here the details of the simulation software. These will become more apparent within the Sections below devoted to the descriptions of the hardware and the real-time software. It is, however, worthwhile stating that the simulation software has provided an important tool whenever new modes of system operation are introduced. All such modes can be pre-tested using the simulation package. Some typical examples of the simulation output are shown in Figure 2. Each software variable (such as the gain k) can readily be varied in order to assess its effect, thus allowing realistic choices to be made appropriate to the given operational conditions. In practice, there is generally little need for change. If and when the system is upgraded in future, it is anticipated that the simulation software will once more provide a useful tool; for example, for assessing the effects of alternative filters or different hardware.

3. SYSTEM HARDWARE

3.1 Spin table and torque motor

The spin table was built originally for precision testing of inertial components and is currently mounted on a 6 m concrete plinth which provides a high degree of mechanical isolation. Its

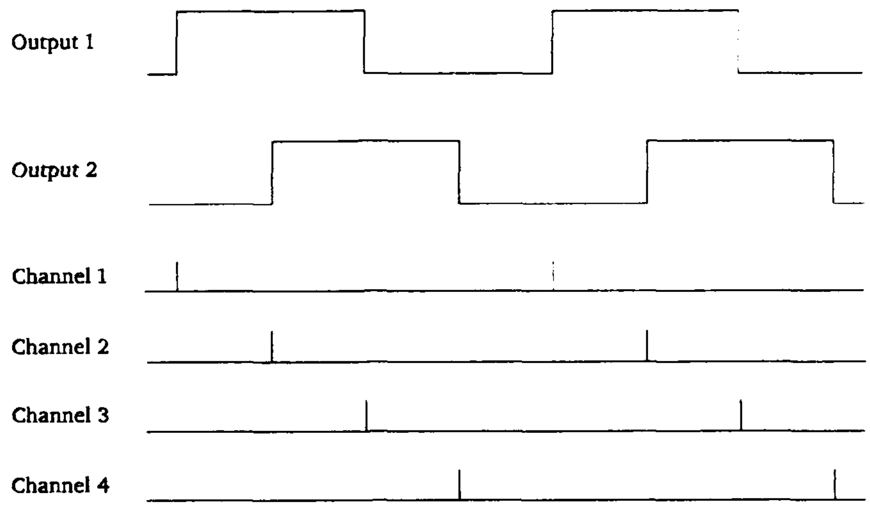


Figure 3 Generation of angular velocity channel data (level-3 interrupts) from position encoder outputs in quadrature

ultimate location will be in the Missile Simulation Centre. The table is driven by an Inland model QT-6401 samarium/cobalt 35 N m torque motor capable of providing 525 deg s^{-2} angular acceleration under no load conditions and of achieving a maximum angular velocity of 1000 deg s^{-1}. When loaded with the cruciform tabletop, missile GCS and optomechanical infrared projection system (total moment of inertia $\sim$ 135 kg m^2), the maximum angular acceleration is reduced to typically 15 deg s^{-2}. The torque motor specifications are listed in Table 1. The motor is powered from a custom-built ± 28 V 23 A power amplifier controlled by the $0-5$ V output from the Metrabyte DAS-16 data acquisition card fitted to the computer.

3.2 Position encoder

The angular velocity can be derived from a low cost Plant Control and Automation 8620 Series position encoder mounted on the base of spin table drive shaft. Two square waves in quadrature are output from the encoder as illustrated in Figure 3, 1000 pulses being generated per revolution; that is, one pulse every 0.36° of rotation.

The pulse counting mode that is standard for determining angular velocity from such an encoder is inadequate for the present spin table control purpose since it provides insufficient velocity resolution, particularly within the lower speed range ($<$ 40 deg/s) of particular interest. Instead, higher resolution data can be derived by measurement of the time elapsed between successive leading or trailing edges of the two output square waves. In this manner, four independent channels of angular velocity data can be derived, two from the leading edges and two from the trailing edges, as also is illustrated in Figure 3. Ultimate resolution is then limited by the 0.36° increment between successive leading or trailing edges on the same output pulse train, rather than by the number of pulses that have been counted in determining the angular velocity measurement. It is noted that the presence of considerable levels of jitter between the two square wave outputs precludes the possibility of elapsed time being measured by comparison of, for example, the position of the leading edge from one square wave and the position of the leading edge from the other.

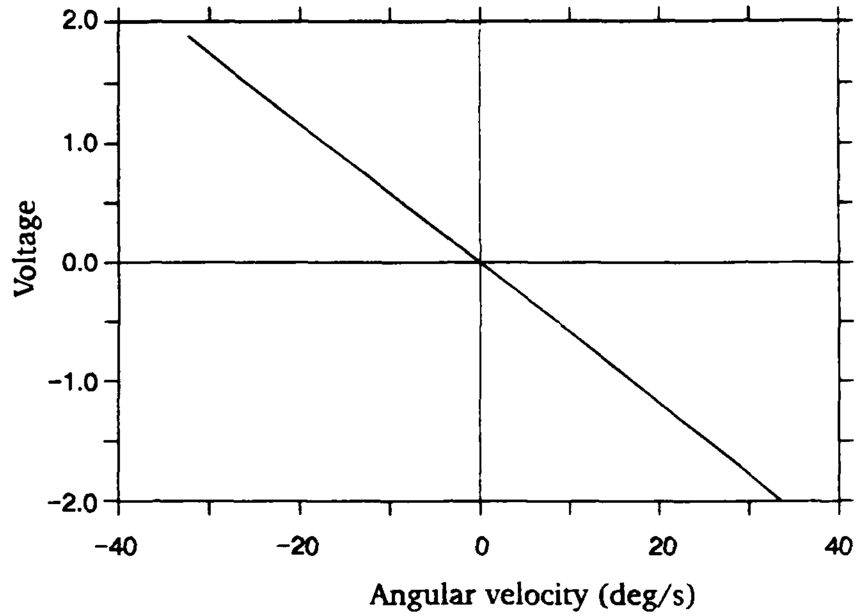


Figure 4 Rate gyro calibration

3.3 Rate gyro

At a later stage during the spin table system development it was decided to introduce a rate gyro mounted on the table as an alternative to the position encoder. A low cost Smith Industries 900 Series single axis rate gyro designed for use in unmanned aircraft was introduced for this purpose. The gyro is non-floated, has no heater and incorporates a brass rotor, optical pick-off and torquer force coil within a closed loop torque balance system. The output voltage is proportional to the coil current and hence to the sensed angular velocity, as seen in the calibration curve shown in Figure 4. The output electronics is bandwidth limited at 12 Hz and the full scale output can be set anywhere between ± 50 deg/s and ± 200 deg/s.

Angular velocity can be measured absolutely and with lower noise using the position encoder, at the expense of more intensive use of the available processing time compared to the rate gyro measurement. On the other hand, use of the gyro frees time for other processing applications. In practice, the gyro has been used during most experiments and calibrated against the position encoder on a daily basis. The programmed calibration procedure is described below in Section 4.3.

3.4 Control computer and interface cards

An IBM compatible 286 machine fitted with a VGA graphics card is the minimum requirement for providing the necessary levels of speed and processing power, together with the general requirements for ease of interfacing and user-friendly display of data. The decision was taken early in the development that all software would be coded in Turbo C. An industry standard (HI-674A) 12 bit Metrabyte DAS-16 data acquisition card (maximum throughput rate of 60 KHZ in DMA mode) is fitted to the computer in order to provide both A/D (16 input channels) and D/A (2 output channels) conversion capability. As described above, the DAS-16 card is used to output a $0 - 5$ V analog control voltage to the power amplifier. The card is also used to read and digitise the gyro output voltage.

Two additional interface cards are also fitted to the control computer: a motor power supply remote card and a position encoder readout card. The remote control card enables and disables the power to both the motor and the power amplifier while the position encoder card has the following functions:

- it provides four separate channels of level-3 interrupts† derived from the two leading and two trailing edges of the square pulses delivered in quadrature from the position encoder.
- it provides a byte that identifies the channel to which the specific interrupt corresponds.
- it provides four 16 bit 60 KHz counters, one for each channel. Each count is processed within the computer in order to provide the elapsed time since the last interrupt for that channel. The counter is reset to zero when the interrupt is received.
- it provides an absolute position count. This count is used to check whether any change in the rotation direction has occurred.

4. CONTROL SOFTWARE

The control software is designed to perform three tasks: to calculate the best estimate of the current angular velocity as derived from the position encoder or rate gyro data, to set the motor control voltage to the level dictated by the control algorithm and to update the user display. In this Section, the programs written for deriving the required real-time motor voltage commands from the position encoder and rate gyro readouts are described, followed by a brief description of the rate gyro calibration program. It is to be noted that there is much commonality among the three programs, all of which are written in Turbo C.

4.1 Position encoder program

This program was the first to be developed and forms the basis for all the real-time programs described in this report. A functional diagram illustrating the principal features of the control program structure using the position encoder data is shown in Figure 5. The complete program listing is available but is not included here.

The three real-time tasks outlined above are executed in parallel. *Control_isr* is the highest priority interrupt service routine, called by level-0 interrupts. Its function is to process data from the 'operational data pool' where the current data is stored and to output the calculated control voltage to the power amplifier used to drive the torque motor. The second highest priority task, *encoder_isr*, is called by the level-3 interrupts output from the position encoder card. Its function is to calculate the current values of angular velocity and angular acceleration and to place them in the new data pool. *Encoder_isr* can be interrupted by the higher priority routine *control_isr*. The least important routine is the screen update which is run as a background task whenever free clock cycles are available. It also provides a check on keyboard input which, when it occurs, is interpreted as a command to immediately terminate the table motion.

† In personal computer hardware, interrupts are assigned in order of priority as follows: level-0: timer; level-1: keyboard; level-2: enhanced graphics adaptor; level-3: communications; level-4: communications; level-5: fixed disk; level-6: diskette; level-7: printer.

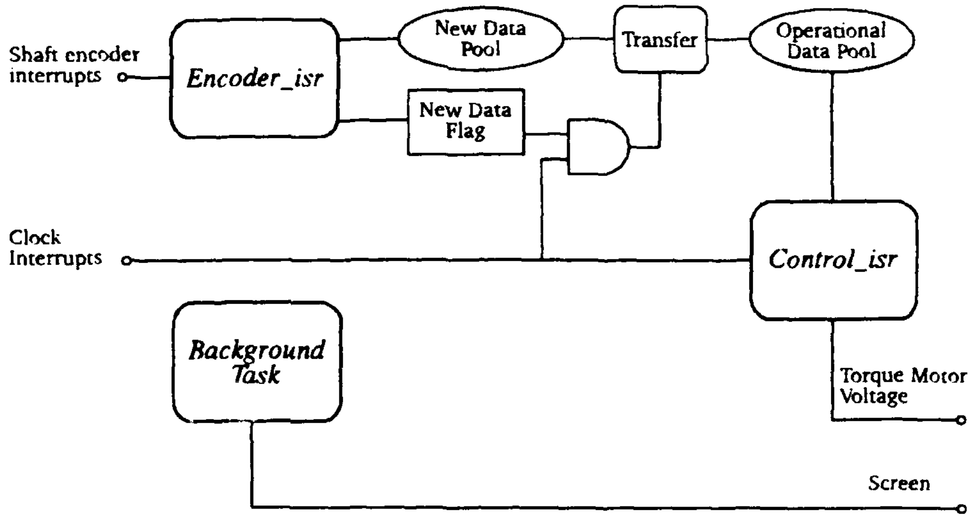


Figure 5 Position encoder control program structure

4.1.1 Control_isr

The basic function of *control_isr* is to set the control voltage delivered to the power amplifier. The routine is executed every 5 ms in response to the level-0 interrupts generated each time the computer real-time clock counter decrements to zero. Normally, such interrupts are generated every 54.9 ms. For the present purpose, however, the time between interrupts has been reduced to 5 ms by appropriate reprogramming of the maximum count held by the decrement counter.

When *control_isr* commences, the first operation to be executed is a check on whether fresh data has been received from *encoder_isr*. If so, the operational data pool is updated and the new data flag is reset. Time is then calculated from the number of times *control_isr* has been executed since the table spin commenced, stored as a variable called *current_time*.

According to the control algorithm shown in Figure 1, the error in angular velocity is established by subtracting the current value of angular velocity from the current value of the demanded angular velocity. The latter is calculated from the preset input variables and choice of input function. Examples of the input function include a constant angular velocity, a sine wave and a sawtooth wave.

In effecting this process, the variables ***velocity***, ***acceleration*** and ***mid_time***, calculated within *encoder_isr* (and labelled by the appropriate channel number) are transferred from the new data pool to the operational data pool. Note that all values are determined at the time *mid_time* midway between the level-3 interrupt and its predecessor. The current value of angular velocity may then be calculated from the equation of motion

$$current\_velocity = velocity + acceleration * (current\_time - mid\_time).$$

The effect of the above calculation is to linearly extrapolate from the value of the angular velocity at *mid_time* to that consistent with the current time. The instantaneous value of the velocity error may then be calculated simply as the difference

$$velocity\_error = demanded\_velocity - current\_velocity\,.$$

Its value is placed at the top of a circular list from which the integrated error contribution to the input filter may be derived (as the product of the sum of the errors accumulated on the list and the time interval covered by the list, divided by the integral scale factor T, consistent with Figure 1). The duration of the list is one of the variables that can be preset by the operator before a run commences. Currently, it is most often set to 50 ms, a value sufficiently large to damp the high frequency electrical noise contributions but insufficient to significantly affect the system temporal response.

In following the control algorithm illustrated in Figure 1, the instantaneous and integral contributions to the velocity error are added and scaled by the gain k. The consequent drive voltage is then rescaled to match the DAS-16 card D/A output range, 0 V corresponding to a maximum drive in the negative direction, 2.5 V corresponding to zero drive, and 5 V corresponding to maximum positive drive. The drive voltage range of ± 28 V is restored within the power amplifier electronics.

The final action of *control_isr* is to provide a check on whether *current_time* exceeds a maximum run time preset by the operator. If so, the drive demand is immediately reset to zero, thus forcing the table spin to slow under control until the motion stops, at which time power is removed from the power amplifier and torque motor.

4.1.2 *Encoder_isr*

The principal function of *encoder_isr* is to calculate the current values of angular velocity and angular acceleration from the position encoder data. The routine is called whenever a level-3 interrupt is received from the position encoder interface card.

On receipt of the interrupt, the byte identifying the position encoder channel number (1 to 4) is read from the position encoder interface card and the accumulated count is read from the absolute position counter. The latter is used to determine whether a change in direction has occurred (by comparison with previously stored values).

It should be noted that hardware problems were being experienced at the time when the software was being developed, in that it was proving difficult to latch the count held by the 60 KHz clock on the position encoder interface card before it was reset by the level-3 interrupt and therefore before it could be read. Clearly, angular velocity can readily be calculated if this count is available. At the time, there was a pressing need to pursue the electronic development of the spin table power amplifier. Rather than await the completion of the position encoder readout hardware it was decided to seek an alternative software solution to the angular velocity measurement problem. That solution, which is an interesting example of the way in which the on-board computer clocks and interrupts can be utilised, has proven to be quite satisfactory and remains in use today.

The basic problem is to determine precisely the time at which each level-3 interrupt occurs. Three contributions must be combined:

1. The value of the variable *current_time* stored by *control_isr*, consistent with the receipt of the last level-0 interrupt.

2. The time increment between receipt of the level-3 interrupt and receipt of the last level-0 interrupt. This is calculated as a fraction of the 5 ms time interval between successive level-0 interrupts, by comparison of the instantaneous count held by the clock decrement counter with its known maximum count (the latter occurring immediately after each level-0 interrupt is generated).

3. An additional increment that allows both for the time elapsed during the reading of the position encoder interface data and for any additional time delay caused by the receipt of a higher priority interrupt. This increment is calculated from the instantaneous count held by the 60 KHz clock and must be subtracted. Note that the 60 KHz clock is reset to zero at the time that the level-3 interrupt is generated.

The average angular velocity between the current and last level-3 interrupts may then immediately be calculated in degrees/s as

$$velocity = 0.36^{o}/(time - last\_time).$$

The average angular acceleration is also calculated by comparing the last two angular velocity values:

$$acceleration = (velocity - last\_velocity)/(time - last\_time).$$

The velocity, acceleration and time are then written to the new data pool and the new data flag is set, to be read by *control_isr* at the time of the next level-0 clock interrupt. We note again that the time to which the measurements corresponds is that midway between the last two level-3 interrupts received from the channel of interest.

A special case occurs immediately after a change of rotation direction is detected. In this case the total angular movement between the receipt of successive same channel level-3 interrupts is unknown. In order to correct for this effect, the *last_velocity* variable for each channel is set to zero within the operational data pool and the *last_time* variable is set to the time at which the first level-3 interrupt following the direction reversal is received. The next three level-3 interrupts then use a reduced angular displacement equal successively to $0.36^{o} * n/4$ (where n = 1,2,3) in the velocity calculation. This method of estimation has proven to be quite satisfactory in spite of the fact that some uncertainty is introduced, originating from the jitter that exists between the position encoder channels.

4.1.3 Background task

The background task is a simple repetitive loop that transfers data to be displayed on the screen; for example, the current value of angular velocity or the time elapsed since the table spin commenced. The values of any other variable may be displayed by operators requiring additional run information. The termination condition is also checked, arising from the press of any key or from the preset condition for task completion being met. The background task is assigned the lowest priority of the three parallel processes and operates continuously whenever the CPU is not otherwise engaged.

4.2 Rate gyro program

The processing procedure is greatly simplified when the rate gyro is used as the control element since the gyro voltage is available whenever a level-0 interrupt is generated, thus eliminating the need for an interpolation/extrapolation routine like *encoder_isr*. Only two tasks need to be executed in parallel: the screen update background task described above and a new control interrupt service routine, again named *control_isr*.

Control_isr operates similarly to the version described above, except there is no need for a velocity update calculation since the measured angular velocity is available on an essentially instantaneous basis. The rate gyro voltage is read from the DAS-16 card whenever a level-0 interrupt is received and is immediately converted to the measured angular velocity by application of the voltage/velocity calibration data. The computing time is sufficiently short that there is no need to calculate and store angular acceleration information. Thus the control algorithm can be implemented without delay in the same way as has been described above in Section 4.1.1.

4.3 Rate gyro calibration program

A special calibration program has been written to enable the rate gyro to be calibrated against the position encoder on a daily basis. When this program is executed, the table is controlled from the position encoder output and is programmed to settle successively for 20 seconds duration at 20 different values of angular velocity (both positive and negative) covering the entire range of interest. Between 1000 and 6000 individual measurements of position encoder angular velocity and gyro voltage are stored during the central 15 seconds of each velocity step. The data are grouped into 48 successive averages which are written to file.

The operator compares the newly acquired data set with the calibration data that already exists, using the screen graphics. If there is any significant difference, then the calibration data file is overwritten.

4.4 Speed limiters

The maximum angular rate of the table is limited in two ways. Firstly, when the user-supplied velocity demands are being read before a run commences, a check is made to ensure that the demands lie within the allowable limits. If not, a prompt informs the operator of the problem and a new velocity is requested. Secondly, the current value of velocity is read whenever the table is spinning and is compared to the allowable range. If it lies outside that range, a termination condition is satisfied and a stop command is issued. The table is then brought to a halt under computer control and power is removed from both the power amplifier and the motor.

5. PERFORMANCE

The spin table control system has been operated successfully within Guided Weapons Division over the past two years, the only modifications being occasional software upgrades usually associated with the need to synchronise the spin table motion with other computer-controlled optomechanical equipment. The table responds satisfactorily to a constant speed demand over the range 1 – 40 deg/s. Examples of step-function responses to mid and low speed demands are shown in Figure 6 respectively. Note that the measured noise levels are further damped by the low pass filter action

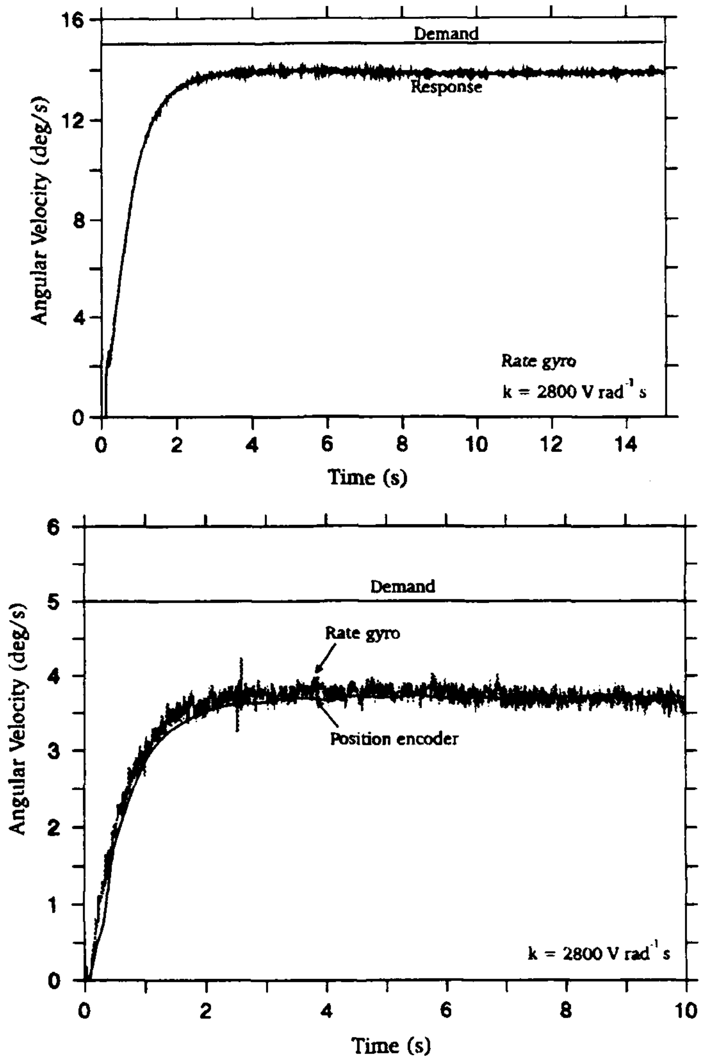


Figure 6 Observed step-function responses

of the table moment of inertia. The table motion is therefore considerably less noisy than that indicated by the motion sensors.

Position encoder controlled operation at high angular velocities is limited ultimately by the frequency at which level-3 interrupts are sent to the computer. The control software described above has been designed under the premise that the rate at which the level-3 interrupts are generated will not approach too closely to the 200 Hz rate at which the level-0 interrupts are generated. This premise becomes invalid when the table spins at angular velocities above about 40 deg/s, with the result that inadequate time is available for the processing steps to be completed before new position encoder data is received. Currently, this limitation is not of concern since 40 deg/s exceeds the maximum speed requirement for the experiments being conducted. It is anticipated, however, that in future there may be a need for improvement. At such a time it is planned to add a divide-by-ten circuit to the position encoder interface board, designed to be activated under computer control whenever the angular velocity exceeds a preset value. In this way, the frequency of level-3 interrupts can be reduced by a factor of ten and adequate amounts of processing time restored.

The low speed performance is limited by several factors. Stiction affects both modes of control and at low speeds is somewhat unpredictable, being dependent to some extent on the angular

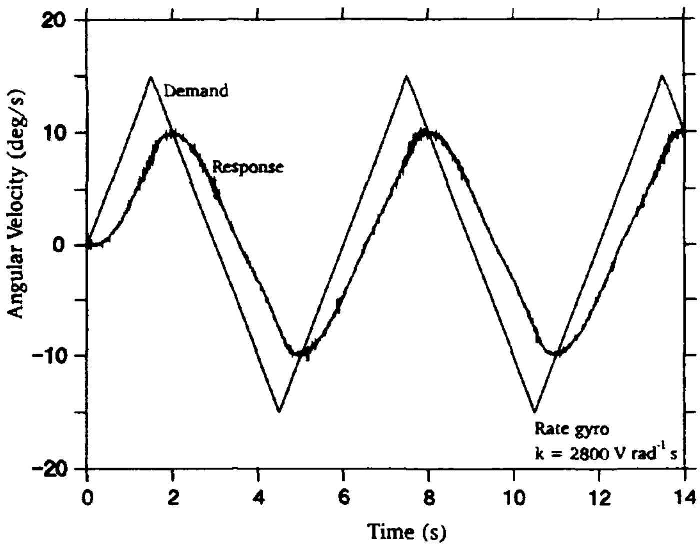


Figure 7 Sawtooth wave response

position of the tabletop. The rate gyro control mode is limited at low speed by the effects of the electrical noise injected during data transfer via the slip rings while the position encoder mode is limited essentially by the excessive time interval between successive level-3 interrupts. In both cases, the gain must be lowered when a low angular velocity is demanded since otherwise a slow oscillatory motion results. Although lower values of gain lead to a comparatively large steady-state error between the demanded and actual velocities (refer to Figure 6), in practice this is of little consequence since it is the actual velocity rather than the demanded velocity that is of most interest and the former can readily be measured. In practice, satisfactory stable low speed performance can be achieved at speeds down to about 1 deg/s. There is currently no need to extend this range to lower speeds.

The level of noise generated by the system is clearly apparent in Figure 6(b) where it can be seen that the gyro control mode is the greater affected. This can be easily understood. Since the interrupt data from the position encoder is transferred in an essentially digital form, the position encoder mode of control is relatively immune to noise. The uncertainties arise from the precision to which the encoder elements have been manufactured, together with quantum errors from the count read from the 60 KHz clock on the position encoder interface board. These add in quadrature to give rms noise levels of typically better than ± 0.02 deg/s, consistent with the data seen in Figure 6(b).

The control data generated by the gyro is considerably more susceptible to noise than is the alternative position encoder generated data. The noise voltage generated by the torque balancing system within the gyro is about ± 1 mV rms, to which random noise spikes of around ± 2 mV rms are added. The resulting contribution to the angular velocity noise can readily be calculated from the gyro calibration data as about ± 0.05 deg/s rms.

The analog transfer of data from the gyro mounted on the spin table, through the slip rings and thence along a twisted wire pair to the DAS-16 card fitted to the control computer, constitutes an additional noise injection path along which typically ± 3 mV rms is contributed. In addition, occasional noise spikes occur, reaching amplitudes of between ± 30 mV and ± 60 mV. Fortunately, the effect of these can be easily corrected within the software by introducing a demand that new velocity data will only be accepted if it lies within several standard deviations of the last accepted value. Since new data is generated every 5 ms and in that time the angular velocity can only have changed by the maximum amount of 0.075 deg/s (given the maximum table acceleration capability of 15 deg/s^2), no significant lag is introduced through this error check.

The response to a sawtooth demand is shown in Figure 7. The phase lag is consistent with that predicted by the simulation, as is the inability to achieve the maximum demanded velocity swing. Nevertheless, zones of constant acceleration are clearly evident, certainly adequate for the purposes of the present experimental program.

6. SUMMARY

In this report, the control system that has been used successfully over the past two years for controlling the angular velocity of the Guided Weapons Division spin table has been described. It has been shown that a versatile system operated under computer control has been designed and implemented, to the point where its day-by-day application is now routine.

It is accepted that there may be future needs for the control system to be upgraded, perhaps to provide a larger speed range, greater noise immunity or improved low speed operation. Given the largely software nature of the control solution that has been implemented, it is not expected that such upgrades will result in a major redesign exercise.

REFERENCES

1. K.D. Scott and O.M. Williams, "Guided Weapons Division Spin Table Facility: Mechanical and Optomechanical Aspects", ARL Technical Report, in preparation.

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16. ABSTRACT

The control system developed and used successfully over the past two years for controlling the angular velocity of the Guided Weapons Division spin table is described. The philosophy underlying the design is discussed, followed by description of the specific hardware and software components and the performance of the sytem as a whole. The report forms part of the permanent record of the GWD spin table facility development.

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